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STOCKPILE TRITIUM PRODUCTION FROM FUSION

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1. Introduction

It is likely that the aging Savannah River production complex will have to be replaced around the turn of the century. In looking ahead toward this eventuality, planners would do well to note the progress in magnetic fusion research during recent years.

Magnetic fusion as a source of neutrons to breed tritium (or plutonium) has a number of potential advantages compared to fission reactors. Perhaps most important is fusion's expected lower capital cost for large scale production. Even though fusion is a new technology, one can make this statement with some confidence based on the physical fact that fusion produces much less heat for a given breeding capacity than fission. The disposal of heat is a major cost driver in fission reactors. Put differently, a relatively small fusion reactor in terms of thermal power output can breed several times as much tritium as a full-scale fission reactor. Thus, if the fusion breeder were developed, stockpile planners would have the option of a large breeding capacity per reactor at little additional cost ("dialable" reserve capacity). This important advantage of fusion over fission is developed more fully in Sect. 3.

Though magnetic fusion is still in the research stage, the time scale for its development can meet future military needs if steps are taken soon aimed specifically at developing the nuclear technology required for materials production. The present magnetic fusion energy program will probably demonstrate the feasibility of one or more plasma confinement concepts by 1995. In parallel with this, a nuclear technology development program specific to materials production applications could be carried out along the

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lines suggested by the DOE FINESSE study aimed at energy applications.[1] This program would consist of modest steps in the next few years, followed by a nuclear technology test facility capable of producing about 20 MW of fusion power. By reusing existing equipment, the MFTF at Livermore could be upgraded to serve as such a test facility by 1995 or earlier.

2. Future Stockpile Requirements for Nuclear Materials

The nation will have a continuing need for an assured supply of tritium as long as nuclear weapons exist. Today's typical weapons require tritium, which decays with a 12-year half-life and must be replaced. While arms control measures may eventually reduce the stockpile, for the foreseeable future, stockpile planning must continue to meet today's realities. Moreover, certain changes in the makeup of the stockpile, underway or being considered, could actually increase the need for tritium even if the number of weapons declines. Steps toward "modernization" of weapons, such as "safer" high explosives, or new missions calling for tailored effects, may lead to weapons with substantially higher than typical amounts of tritium. Long-range nuclear materials planning requires assuring plutonium production as well.

Today, tritium is produced in the U.S. only at the Savannah River complex. The reactors at Savannah River will be about 50 years old by the year 2000. Thus, planners must be prepared for their replacement about that time.

Presumably such long-range planning will examine new technologies that might become available if they offer advantages over the present technology. Fusion may be such an option.

3. The Fusion Breeder

The two main ingredients of a fusion breeder are the burning plasma, which is the business of neutron driver development discussed in the next section, and the surrounding "blanket" where the breeding function is carried out. Neutrons produced by the plasma react with lithium in the blanket to produce tritium (or plutonium, if the blanket contains uranium). Since the deuterium-tritium (DT) reaction in the plasma consumes one triton in producing one neutron, it is also necessary to multiply neutrons in the blanket.

One approach, which minimizes heat production in the blanket, is to multiply neutrons by the (n,2n) reaction in beryllium imbedded in the blanket. In this way, the blanket can be designed to produce 1.6 useful neutrons per fusion reaction. These neutrons breed 1.6 tritons, and hence, an excess of 0.6 tritons per fusion reaction for a total energy release of about 25 MeV (see Table I). As is shown in the table, fission can also yield a net 0.6 triton per fission reaction, but with an energy release of 200 MeV.

As was noted above, the lower energy release per neutron from fusion is an advantage for breeding applications. For both fusion and fission, breeding capacity (proportional to neutron production) is proportional to thermal power, but fusion produces eight times less power relative to breeding capacity. Since reactor capital costs tend to scale with thermal power, from the outset a fusion breeder has an 8 to 1 cost advantage relative to fission. In small fusion breeders, this large cost advantage is offset by the cost of plasma technology (magnets, etc.) required to confine the burning plasma. However, plasma technology costs do not scale directly with power; for example, tokamak magnet costs scale with the plasma surface area whereas power scales with plasma volume. Consequently, since the heat-related costs are the smaller part, the capital cost of a fusion breeder is relatively insensitive to thermal power and breeding capacity over a wide range (see Fig. 1).*

The relative insensitivity of fusion capital cost to breeding capacity offers stockpile planners a new option in dealing with the uncertainties in forecasting long range requirements discussed in Sect. 2. If there were little cost penalty in adding capacity, one could choose to build-in reserve capacity as each old reactor is replaced. Moreover, with the fusion breeder, this reserve capacity could be "dialed" up and down as needed by operating the machine at a higher or lower plasma density, or by planned outages.

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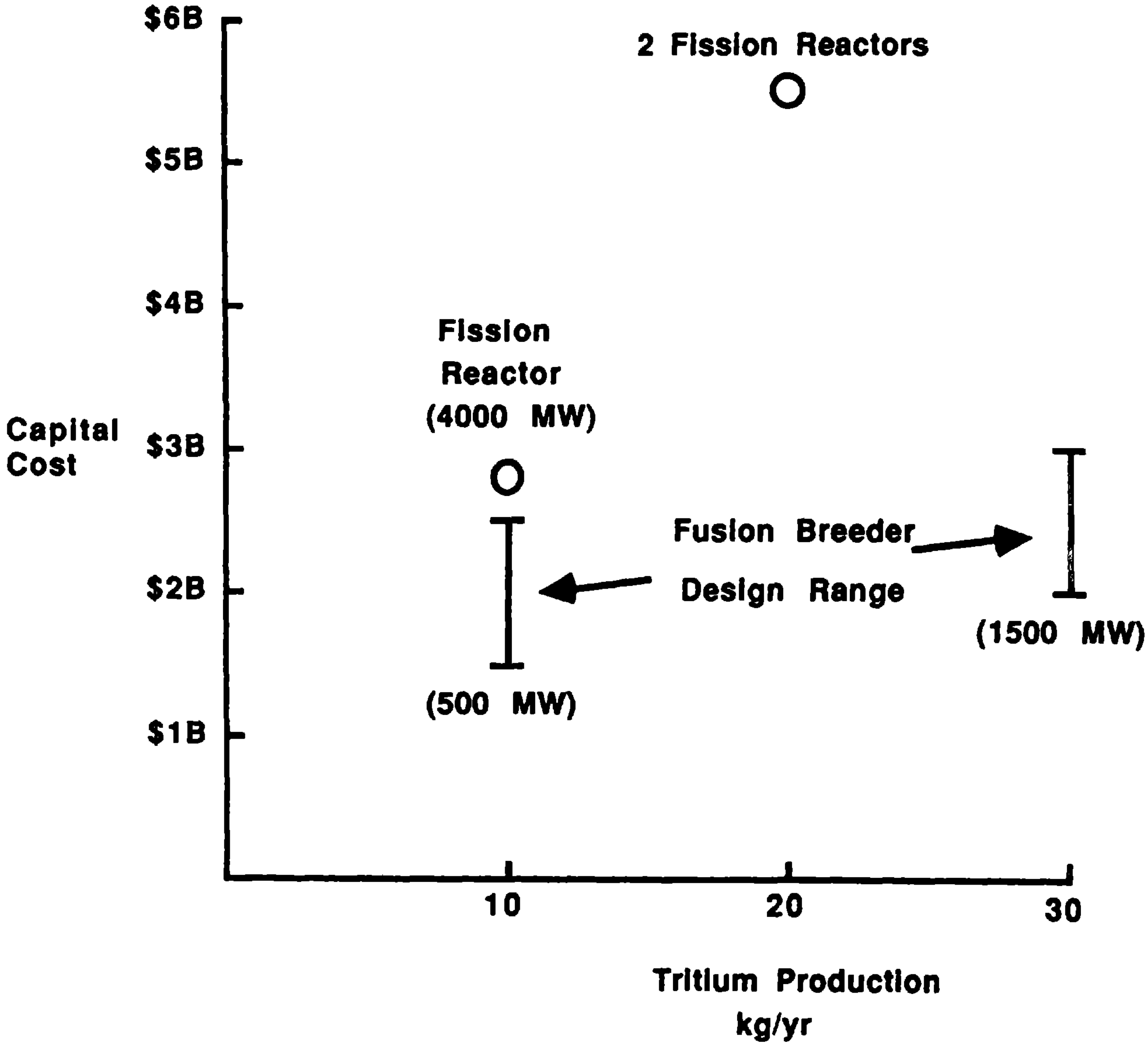
*Figure 1 represents the envelope of a family of costs and cost scalings for mirror and tokamak designs. For example, cost estimates for 500-MW mirror and tokamak reactor designs (2) yield $1.6B for both designs when converted to 1986 dollars. (A conversion of 1.16 for 1982 to 1986 dollars was used.) The cost of mirror and tokamak designs in this power range scales approximately as Power$^{0.3}$ and Power$^{0.4}$, respectively. This gives values for 1500-MW designs of $2.2B and $2.5B, respectively. The upper end of the range of costs shown allows for contingency and for the possibility of additional costs when more detailed studies are done.

TABLE I. FUSION AND FISSION TRITIUM BREEDING REACTIONS

Fusion Breeder		
D + T	→	n + 17.6 MeV
n + Be (multiple reactions)	→	2.3 n - 0.7 n (absorption plus leakage)
1.6 n + Li (multiple reactions)	→	1.6 T - 1 T (consumed plasma) + 12 MeV
D + T + blanket	→	0.6 T + 25 MeV
Fission Breeder		
Fission Reaction	→	2.5 n - 0.9 (absorption plus leakage) - 1 n (fission capture) + 200 MeV
0.6 n + Li (multiple reactions)	→	0.6 T
	→	
Fission Reaction	→	0.6 T + 200 MeV

Fusion can provide wide range of breeding capacity at low additional cost



"Dialable" reserve capacity would add an important new capability for long range stockpile planning

Fig. 1. Fusion's economy of scale permits reserve capacity for a modest increase in reactor mass (roughly $\propto$ cost).

In addition to their flexibility to provide reserve capacity at reasonable cost, fusion breeders would be easier to site because they produce less waste heat relative to capacity. Also, fusion produces much less radioactive waste than fission. For tritium production by fusion with a beryllium neutron multiplier, the only radioactive waste is due to neutron activation of the blanket structure, which can be minimized by a proper choice of structural materials.

Finally, a fusion breeder designed for tritium production could equally well be adapted to plutonium production with different blanket inserts. With a modular blanket design, which is also best for maintenance purposes, a single fusion machine could produce either tritium or plutonium or the two in combination. Moreover, with a beryllium multiplier, fission is largely suppressed in a plutonium-producing module, so that the advantages of less waste heat and less radioactive waste are largely retained even for the production of plutonium.

4. Progress Toward a Fusion Neutron Driver

Because the fusion driver for a production facility would be smaller than a fusion power reactor, the present status of magnetic fusion research is, relatively speaking, more advanced for the purpose of breeding tritium than for energy applications. Two of the three largest existing tokamak facilities, the TFTR at Princeton and the JET in Europe, are designed to produce neutrons at a fusion power level of tens of megawatts for brief periods, and the DOE is already discussing a follow-on to the TFTR that would be fully ignited for a few seconds at a time at the full power level of a production facility driver by 1995.

The initial neutron-production experiments in the TFTR could be carried out before 1990 if the present series of experiments aimed at demonstrating plasma heating and confinement continue to do well. Thus far, energy confinement times of 0.5 sec or more have been demonstrated in pure deuterium plasmas, and equipment is being installed to heat the plasma to the high temperatures (around 100 million degrees Kelvin) necessary for fusion reactions to occur. These experiments are the culmination of twenty years of steady progress in tokamak research, during which plasma temperatures have increased a hundred-fold, and the magnetic insulation of plasma heat as measured by the well-known Lawson criterion has increased a thousandfold. Another fusion driver concept that could possibly be available by 1995 is the tandem mirror, discussed below. The DOE also conducts research on other potential driver concepts at an earlier stage of development.

Given the above rate of progress and the continuing interest in magnetic fusion around the world, it appears likely that a fusion driver suitable for a nuclear materials production facility will be developed by 1995 as stated earlier.

5. Program to Develop a Fusion Production Module by 1995

While priorities in the present magnetic fusion program favor the development of a suitable neutron driver by 1995, a diminishing urgency for energy applications and recent budget reductions could cause a considerable delay in work on fusion nuclear technology (blankets, etc.). Moreover, a production module with its beryllium neutron multiplier and emphasis on neutrons rather than heat would differ significantly from a blanket module designed to produce electricity. Thus, a specific program to develop blanket modules for nuclear materials production is needed if fusion is to become a viable option for a new production complex.

The goal of a materials production technology program should be a full systems integration test of a working production module by 1995, commensurate with the rate of development of the driver. The blanket and other nuclear components for production can be based on known technology and, therefore, the issues are those of design, not feasibility. Because the production blanket runs cool, it poses fewer technical issues than a blanket for electric power production. Nonetheless, thorough systems integration tests to determine reliability, fault modes and design flaws are essential before commiting to a production facility based on fusion.

Based on the FINESSE study carried out by the magnetic fusion energy program,[1] the least costly means to test nuclear technology in a realistic neutron environment would be a small fusion device producing about 20 megawatts of power. The tandem mirror fusion concept is a prime candidate for this purpose; also, a single yin-yang mirror. In recent years both LLNL[3] and KfK Karlsruhe[4] have proposed tandem mirror nuclear technology test facilities, and earlier LLNL proposed a yin-yang design (the FERF).[5] By reusing expensive equipment already in place, a nuclear technology test facility of either mirror design could be built as a follow-on to the Mirror Fusion Test Facility (MFTF-B) at Livermore. This test facility could operate by 1995 or earlier.

6. Summary

A fusion breeder holds the promise of a new capability - "dialable" reserve capacity at little additional cost - that offers stockpile planners a new way to deal with today's uncertainties in forecasting long range needs. Though still in the research stage, fusion can be developed in time to meet future military requirements. Much of the necessary technology will be developed by the ongoing magnetic fusion energy program. However, a specific program to develop the nuclear technology required for materials production is needed if fusion is to become a viable option for a new production complex around the turn of the century.

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